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# Virtual Reality Environment for Studying Change Blindness

Bachelor's Thesis (9 ECTS)

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# Virtual Reality Environment for Studying Change Blindness

## **Abstract:**

Change blindness is a counterintuitive phenomenon which describes the inability to detect changes in the surrounding world. Change blindness is studied by using various methods. However, so far there are only a few studies in virtual reality environments. This is the case despite the fact that studies done in virtual reality have advantages over conventional means of doing experiments. The aim of the present thesis is to develop a toolbox that allows one to easily prepare, reproduce and carry out change blindness experiments in virtual reality. For this, toolbox enables to design levels by modifying objects' position, appearance and adding new ones. Also personalised experiments can be created and executed.

**Keywords:** change blindness, virtual reality, head-mounted display, toolbox, freeware

## Virtuaalreaalsuse keskkond muutusepimeduse uurimiseks

### **Lühikokkuvõte:**

Muutusepimedus on intuitsioonivastane fenomen, mis kirjeldab võimetust märgata muutusi ümbritsevas keskkonnas. Muutusepimeduse uurimiseks on kasutusel erinevaid meetodeid. Kuigi virtuaalreaalsuses läbiviidavatel katsetel on mitmeid eeliseid võrreldes tavaliste meetoditega, on virtuaalreaalsuses läbi viidud vaid üksikuid uuringuid. Antud lõputöö eesmärgiks on arendada tööriistakast, mis võimaldab katseid ettevalmistada, taastada ja virtuaalreaalsuses läbi viia. Tööriistakasti abil saab disainida ruume, lisades uusi esemeid, muuta nende asukohta ning välimust. Lisaks eelnevale saab ka koostada ja läbi viia isikupärastatud katseid.

**Võtmesõnad:** muutusepimedus, virtuaalreaalsus, pea külge kinnitatud ekraan, tööriistakast, vabavara

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## Introduction

Change blindness (CB) is a counterintuitive phenomenon, which describes the inability to notice even large changes in scene [1]. The phenomenon drew a lot of attention of the researchers in the 1990s [1]. On figure 1, there are some example photos with several differences. For example, in case of these photos, many viewers fail to notice that on the right picture the tree branch is missing.



Figure 1: Example photos of change blindness [2]

Furthermore it is believed that change blindness may be causing traffic accidents and errors on eyewitness testimonies. In traffic, driver has to detect many changes and because of the phenomenon some crucial changes may be unnoticed, which may lead to an accident. Given its importance, it would be interesting to explore this phenomenon in realistic but controlled settings. However, until recent time there have been technical reasons that have made it difficult to carry out such experiments.

To start with, the studies are mainly done by showing alternately two similar pictures, which have some differences [3]. The issue here may be that pictures are shown in a static two dimensional way, but we sense the surrounding world in three dimensional (3D) way that is constantly changing. Because of that, the method may lead to inaccurate results. Thus the best way would be to carry out experiments in a real world.

However, the problems with real life experiments are cost, preparation time, and reproducibility. Although there are some clever ways to change objects in real world, so that the subject would not notice [4], a better solution for these issues could be a virtual environment.

Currently, there is no three dimensional virtual environment enabling to investigate the phenomenon of change blindness. To solve this issue a head-mounted device (HMD) is planned to use. These devices allow users to see the computer generated world in 3D space while tracking head movements, so user can look freely around the virtual world. This is needed to make experiments in virtual world feel similar to a real environment.

Hence, the main idea of this thesis is to develop easily adjustable and cheap alternative

to real world studies to learn more about change blindness. For that purpose a toolbox is developed that will allow to create and manipulate virtual rooms and make studies in them using virtual reality.

First chapter describes the phenomenon of change blindness and provides a closer look to virtual reality and related studies.

Second chapter describes the toolbox, its capabilities, technical side of it and how a scientist can use it.

In the third chapter one can find the general discussion about the problems that occurred while developing the toolbox, why was virtual reality used and what are the future directions of the present work. Also there is brought out a research executed with the toolbox.

# 1 Background and Related Work

## 1.1 Change Blindness

This chapter provides the background about the phenomenon of change blindness, how change blindness is usually studied, main paradigms and how change blindness affects our everyday life.

### 1.1.1 Concept

Change blindness is a perceptual phenomenon, which describes the inability to detect changes to objects in scene [1]. For example, a pen is seen on the table, after a blink the pen is removed, but the disappearance of the pen is not noticed by the subject. The undetected object can also be a pedestrian, who stepped on a road, a car, getting closer in the front and so on. Luckily paying attention in traffic helps a lot against change blindness. However, it is much harder to detect changes without looking for them. In traffic we know what to expect, but in some situations, when the changes are not expected or attention is distracted even larger changes can remain undetected [3]. For example, in study [4] only half of the subjects noticed that the person who asked help had been replaced in the middle of conversation.

Change blindness is much more likely to happen when we are not looking at the object, blink or saccade (in real world we move eyes 3 to 4 times in a second) [1]. Because of the counterintuitive nature of change blindness it is rather hard to imagine such incapability in our visual perception without knowing the phenomenon [5]. Indeed, even knowing about change blindness, does not help much detecting the changes.

### 1.1.2 Methods of Studying Change Blindness

There are four main ways Change Blindness has been studied.

First of them is by using photos. Photos can be used in various ways. For example, in study [6] subjects were shown hundreds of photos to memorise and later they had to indicate which photos they can recall. Some of the photos experimenters displayed were originals mirrored and interestingly subjects thought these were also shown in the initial set.

Another and more popular way is to flicker between photos [7]. Subjects are displayed two images one by one that are essentially the same except some minor differences. Between the photos a blank screen is shown. This is used to reset eye and to evoke change blindness effect. Flicker process is demonstrated on figure 2.

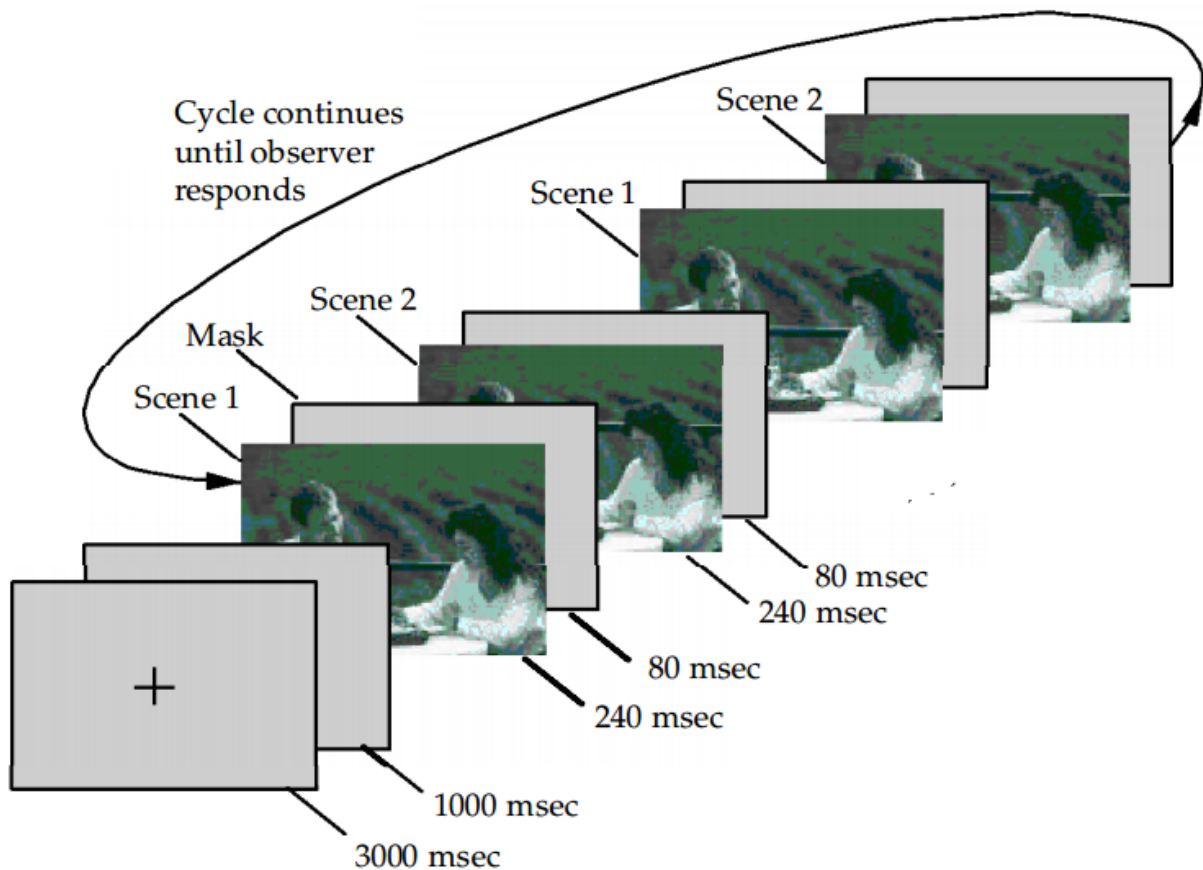


Figure 2: Example flicker experiment flow. Scene 1 and 2 are displayed to a subject for 240 milliseconds in repeated order. Between the scene changes a gray mask is shown for 80 milliseconds. This process continues until the subject responds. Figure taken from [8].

The differences that occur on flickering pictures may be subtle. For example, disappearance of a part of an object, change of an object's colour etc. Some types of the changes are generally more easy to detect. Such changes that involve disappearance of the whole object or changing the position of object. Figure 1 shows the example of the disappearing object on the photos placed side by side.

Second way to study change blindness is using video material. Videos are previously filmed and after that the changes are edited in. In videos changes take place usually between changing camera views (so called "cuts"), because that way it is not so complicated to replace object in scene. In study [9] subjects were shown video and they had to pay close attention to it. This study had 10 subjects and the video had 9 changes. However, only one subject could notice any of the changes. Afterwards subjects had to watch the video for the second time and were told to look for changes. As a result they noticed average of 2 changes (see figure 3).



Figure 3: Frames of the video used in experiment [9]. On this figure one can see sequential changes of the video shown to subjects.

Third method is real world studies. Although it is rather hard to carry out experiments in real world, there are still some studies. For example, in study [4] experimenter asked random persons for the directions, during the conversation experimenter is replaced by another one (see figure 4). Roughly half of the subjects did not notice that the person they were discussing with had changed.





Figure 4: Pictures of real world study. First three pictures show the process of experimenters switch. On the last picture are two experimenters side by side. [4]

Last but not least, doing studies in virtual environments. This type of studies are getting more popular, because the technology is getting more affordable and graphics more realistic. Studies in virtual world are similar in essence with real world studies, especially in virtual reality. For example, Evan A. Suma [10] used virtual environment to study the importance of familiarity of scene in change blindness. They used eye tracking device to record subject's eye movement, which is very hard to do in real world without subject knowing about it. This is also one of many advantages of virtual environment over real life experience.

### 1.1.3 Paradigms

In contrast to methods explained above, paradigms are set of concepts, which are applied to the methods. This means that a method is just a way that a paradigm may be handled.

Here are listed four main paradigms:

1. flicker
2. forced choice detection paradigm

### 3. mudsplashes

### 4. foreground-background segregation

Flicker is the most commonly used paradigm to study change blindness. Flicker stands for showing subjects two constantly changing pictures. Between every change a blank screen is briefly shown to trigger change blindness effect. Without a blank screen the changes are detected easily, but adding a blank screen between changes makes identifying the change much harder [8]. Example flicker test can be found on given websites [11, 12].

Secondly, forced choice detection paradigm. In this case two pictures are shown to subject one by one like in flicker paradigm, except only one difference, subjects can look at each picture only a certain amount of time. After that they have to identify the changes they detected if at all. [7]

Using "mudsplashes" is another way change blindness is studied. Mudsplashes are few high contrast spots over the screen, which appear for short period of time and do not cover the area where change occurs. Real world parallel would be mudsplashes or water spots on car's windshield. Because of this often changes in scene will not be noticed. However, usually subject detects central interest element changes right away, but minor interest changes after two changes or more. Furthermore 13-30% of subjects, depending of change, do not detect minor interest changes at all [13].



Figure 5: Example picture of mudsplashes used for study [13].

Lastly, foreground-background segregation. Like the name indicates images where foreground and background are easily distinguishable are used in these studies. Studies have shown that small changes which take place in the front are noticed much faster than large changes in the background [14].

#### 1.1.4 Practical Impact

This chapter describes change blindness implications in practical world.

Accidents in traffic, caused by lack of attention, tiredness and so on happen all the time. One important question is to what extent such accidents are influenced by change blindness. Driver has many things to keep in mind, for example road signs, pedestrians and other cars. To notice all the changes driver has to look around a lot. However, when a change happens while looking around, driver might not notice this soon enough

as it is much harder to detect changes in scene, while blinking, during saccade or eye movements. In one study [15] was demonstrated that change blindness occurs in driving scenes. However, these results might not be very accurate with respect to real world, because their study used basic flicker paradigm with photos. However, these authors found out that more relevant changes to driving were detected faster than minor changes and changes in left or right on the scene were noticed faster than in centre.

Another crucial field where change blindness has practical implications is eyewitness testimony [16]. Mistaken eyewitness identification can cause problems not only to identifier, but may lead to a situation where innocent person is accused of criminal offence. Because of change blindness effect, eyewitness may mix up criminal with a innocent spectator without even noticing it. That is one reason why witness might point on wrong person at the identification. Studies [4, 17] also indicate incapability to noticing changes related to persons.

Last but not least, noticing changes on user interface is affected by change blindness. For example, some military specialists who have to monitor different screens at the same time might have to look on one screen couple of times before they notice change [18]. Also the change blindness effect has to be taken into account in designing mobile user interfaces. That is because mobile interfaces have many icons to check and it is easy to miss some change in them [19].

## **1.2 Virtual Reality**

Virtual reality (VR) is computer generated environment that allows to simulate feeling of being a part of the virtual world [20]. This chapter describes how virtual reality devices are used and what is Oculus Rift.

### **1.2.1 Use of Virtual Reality Devices**

Virtual reality is widely utilised in different fields and replicates many real life situations. It is used to train for activities, which in real world would be dangerous. For example parachuting, flight simulation and surgery simulation [21]. Also it has big influence on gaming industry.

In this thesis, to mimic reality, head-mounted device (HMD) is used, which tracks users head movements and has separate displays for each eye. This type of device is used to create 3D world and to give feeling of being really in that world. To make experience realistic head movement tracking is utilised, which allows to look around in the virtual environment.[20]

### **1.2.2 Oculus Rift**

This study focuses on using Oculus Rift. Next is a description of Oculus Rift and some reasons why it is used.

Oculus Rift is virtual reality head-mounted display, which uses sensors to follow users head movements and it has two high resolution displays, one for each eye to enable 3-dimensional vision, which makes experience even more realistic [22]. These abilities make Oculus Rift a good candidate to study change blindness effect caused by head movements.

Oculus Rift is used for this toolbox, firstly because it is popular worldwide [23]. Secondly it has well developed software for several gaming engines [22]. Lastly it has many tutorials and majority of problems have solutions available on its own community page<sup>1</sup>.



Figure 6: Oculus Rift Development Kit 2 [24].

### 1.3 Related Work

This part of thesis contains short overview of similar works. These works are not only linked to the field, but also share the approach of this thesis.

There are many studies about finding changes of two flickering pictures, in videos and even in real life experiments. Although a little research has been done in virtual environments, virtual reality is almost left out. Maybe because it is rather expensive, uncomfortable and hard to get started. Despite that, some scientists have still covered this approach. In following paragraphs some papers similar to this thesis are described.

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<sup>1</sup><https://forums.oculus.com/>

One of the works is by Evan A. Suma [10]. In this study, experimenters exploited change blindness phenomenon to make physical space appear larger than it really is. For creating virtual reality they used head-mounted display and head tracking system. In the experiment subjects were redirected in virtual world by changing the position of the door they entered. To make a door change at the moment it is not watched, subjects had a task to turn on a computer monitor or memorise an image on it. For that subjects had to go to the other end of the room. When the subjects went back to the door, they were directed to other way so that they will not exceed physical limitations. Hence, in the physical world, subjects actually circled around, but in virtual world it was not that obvious. As a matter of fact, only a few subjects were certain they were going in circles, but most felt it only a little bit. Furthermore only 1 of the 77 subjects noticed that door has changed position, which is a remarkable result, because it is hard to imagine that such a large change remains unnoticed. Also, whether the task was simply to turn on monitor or memorise the image, the results were not affected.

The other relevant study is written by Hacer (Uke) Karacan [25]. The main idea of this study was to learn to what extent familiarity of the room matters to change detection. For this authors set up a virtual environment, where subjects had to walk across a path. In total, all subjects had to walk 8 circles. After a subject had walked certain number of circles, one object changed. Subjects were divided to two groups: inexperienced and experienced. Subjects who belonged to the inexperienced group walked two times and the members of experienced group walked six times the path before the change occurred. The change was one of the four: appearing, disappearing, moving to another place or replacing with another object. To gather information, experimenters had hardware which allowed to track subjects' eye movements. They gathered data about how long subjects looked at changing object before and after the change had happened. Subjects who belonged to the experienced group looked much longer at the object after the change than the members of inexperienced group. This indicates that in familiar place changes are detected more often than in foreign place.

The main outcome of the present thesis is a toolbox, program which allows scientists to easily create levels and carry out experiments in these levels. In comparison, the mentioned studies [10, 25] are more about answering a specific scientific hypothesis and not about developing a standalone program. Also there are no similar toolboxes, that allow to create own levels and experiments. The similarities to the thesis are that both [10, 25] do experiments in virtual world. In addition, in studies [10, 25] objects disappeared or changed while subject did not look at them, which is similar to the way used in developed toolbox.

## 2 Toolbox

This chapter is about the toolbox developed as a result of the thesis. Including overview and requirements of the toolbox, some technical information and example workflow. Additionally appendix A contains link to supplementary toolbox files.

Toolbox is done in collaboration with Kälver Kilvits, who added memory tests to it and helped to develop overlapping elements. Kilvits also wrote a thesis about his work [26]. Most of the requirements of the toolbox were set by supervisors and psychology student Madis Vasser. The latter used toolbox's experiment part to study change blindness in virtual reality [27].

### 2.1 Overview

As mentioned before, the idea of the toolbox is to enable researchers to carry out experiments easily in virtual reality. For this reason the toolbox allows to create new experiments, build or modify levels and execute experiments.

More specifically, this toolbox contains everything necessary to make two kind of experiments: memory and change blindness. Latter is in main focus for this thesis. To carry out these experiments the user can either load previously created experiment or make their own. In order to make custom experiments, the user can choose any premade level and configure appropriate settings for the experiment. Furthermore the toolbox allows to furnish a level as desired and modify previously made levels. From a change blindness perspective, while creating or modifying a level, user is allowed to mark items that are going to change.

### 2.2 Requirements

This chapter describes functional and non-functional requirements.

#### 2.2.1 Functional Requirements

Firstly is shown figure of functional requirements group set for developed toolbox and secondly these requirements are described more closely.

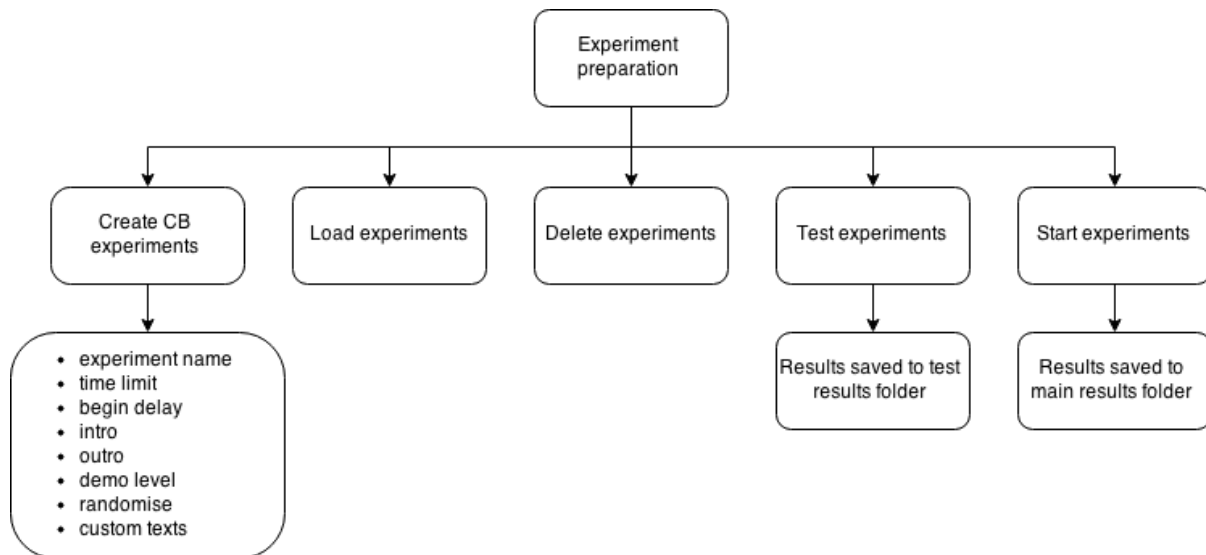


Figure 7: Requirements of experiment preparation.

The first group of functional requirements is about preparing an experiment (see figure 7). The most important part of latter is creating a new experiment. The main idea of this toolbox is to allow users to create different studies. Hence, without ability to create a personalised experiment the amount of studies would be limited. In the release version of the toolbox user has to choose at least one level from available levels list.

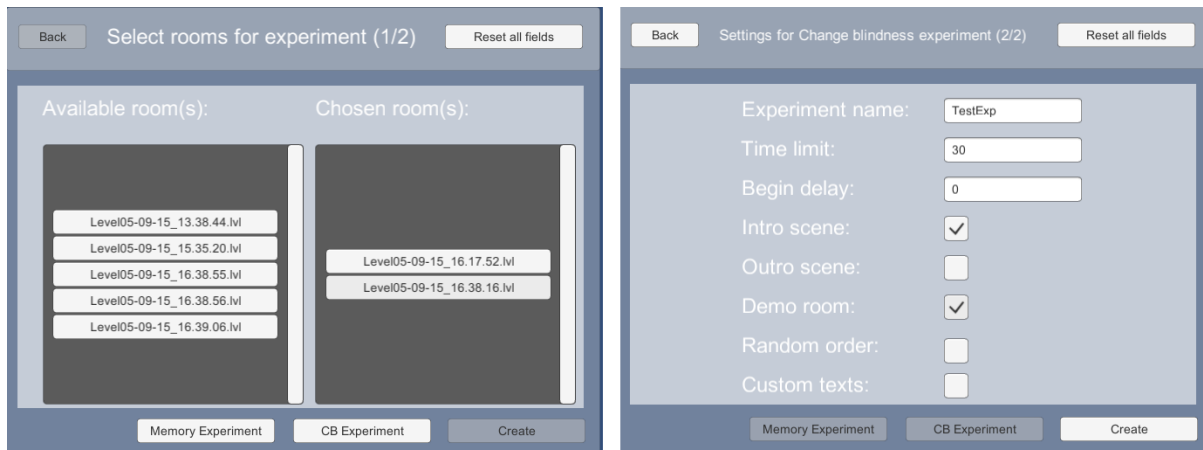


Figure 8: Menu pages of experiment creation. On the left is view of level selection and on the right is view of experiment settings.

User may also configure modifiers before creating an experiment. These are "experiment name", "time limit", "begin delay", "custom texts", "intro", "outro", "randomise" and "demo level". "Time limit" stands for how long a subject can look around in one level, by default it is set to 0, so the time is unlimited. "Begin delay" is time before changes in level starts. "Intro", "outro" and "demo levels" are booleans and means whether intro, outro or demo level is shown or not. Intro and outro are blank levels with purpose of introducing and finishing the experiment to subject. To illustrate, intro may contain following text: "In this experiment, there are 3 levels. The first one is a demo level. For

each level You have 45 seconds to find a changing object. Good luck!". Granted that a modifier "demo level" is selected, the first level of the experiment is for getting used to environment and controls. Custom texts allows user to write their own text for the beginning and ending of the experiment. "Randomise" gives a possibility to randomise level order. After a new experiment is created, user can load that experiment for a testing or studying. Also experiments can be deleted at any time.

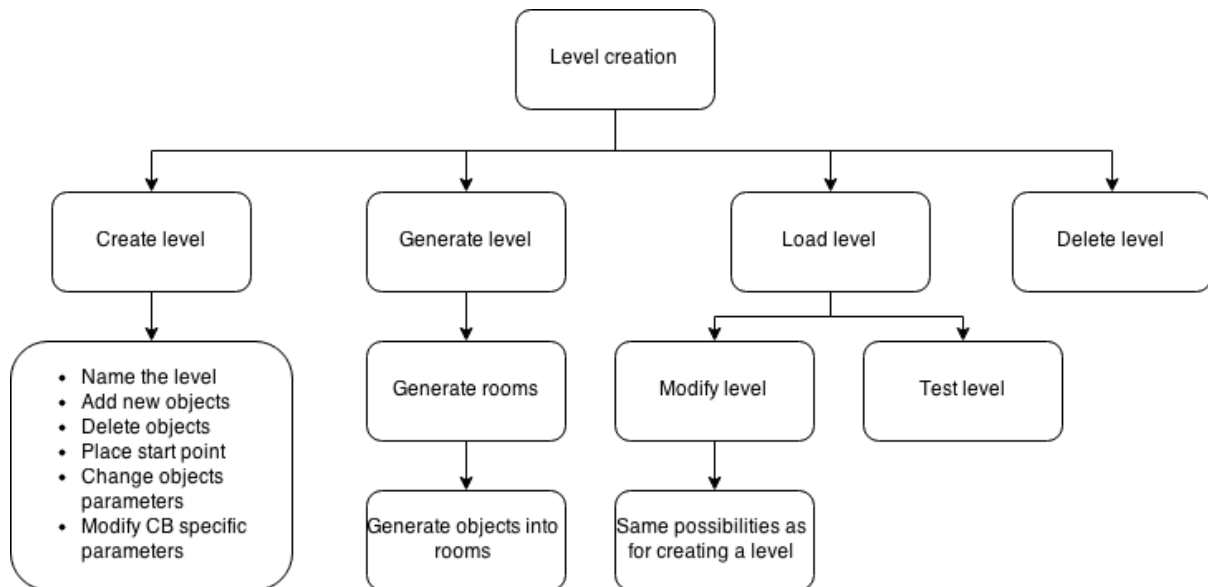


Figure 9: Requirements of level creation.

Another group of requirements is level creation (see figure 9). For putting together a new level there are three different ways. Firstly creating a new level. To create a new level, a base has to be selected. Base is an empty level, which has certain size, shape, room count and floor count. After selecting a base, user has to name the level and insert a starting point. Starting point is the place where the subject stands or starts moving. Having done that, user may start adding objects to level and move them to desired place. Also change the colour and size of the object or remove the object from level. Every added object can be marked as changing object. Changes involve following parameters of an object: transparency, colour and position. When the level is in right condition and saved, then it is ready to be used in experiment.



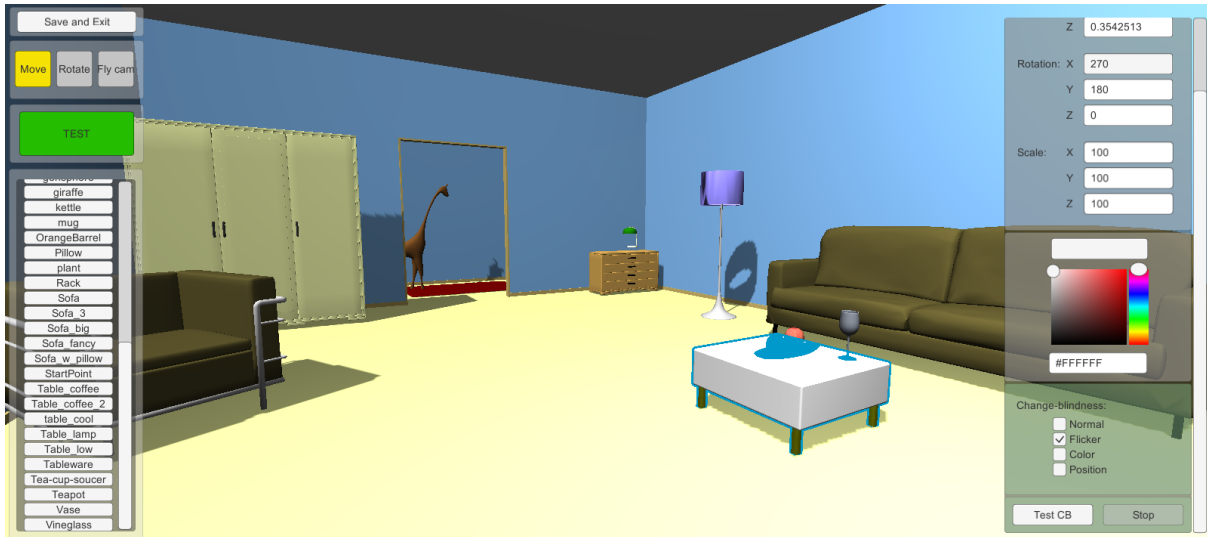


Figure 10: View of the level editor.

Second way to make a new level is by using room generation. To start with, user has to select suitable room base types and how many rooms the level has. After that, program puts the rooms randomly together into a level. Level may be regenerated as many times as user wants. Having achieved desired result user may also let the program randomly generate objects into the level.

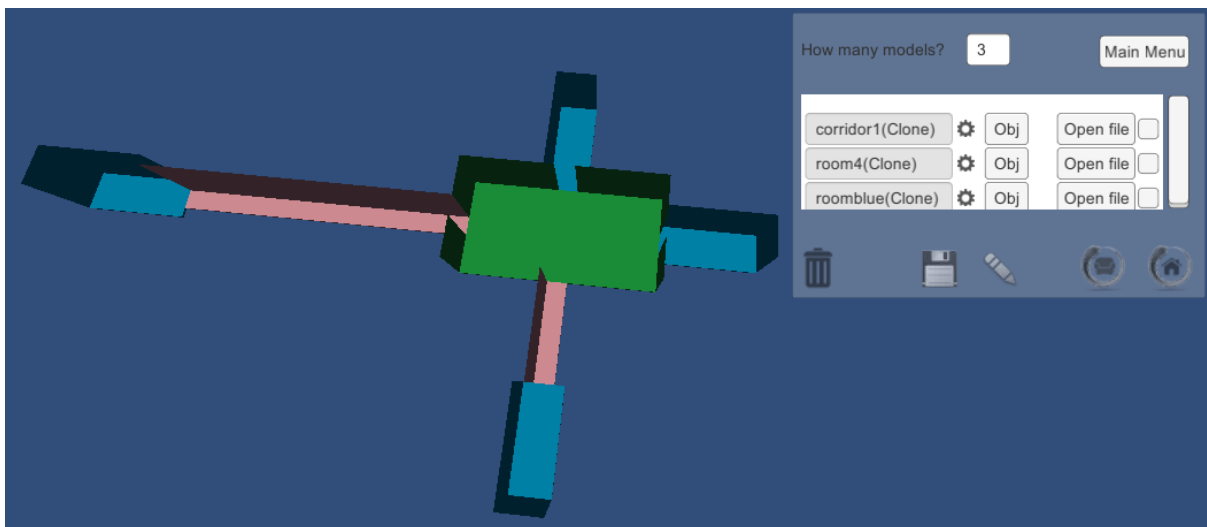


Figure 11: View of the game room generation.

Last way for creating a new level is modifying a level. This option allows user to change any created level. For that user has same possibilities as described in paragraph of creating a new level. When finished user has possibility to overwrite last level or save the modified level as a new one. Hereby any level may be used as a template of a new level. Also while modifying a level, it can be tested. That means user can check how subject would see the level and look for any illogical object placement.

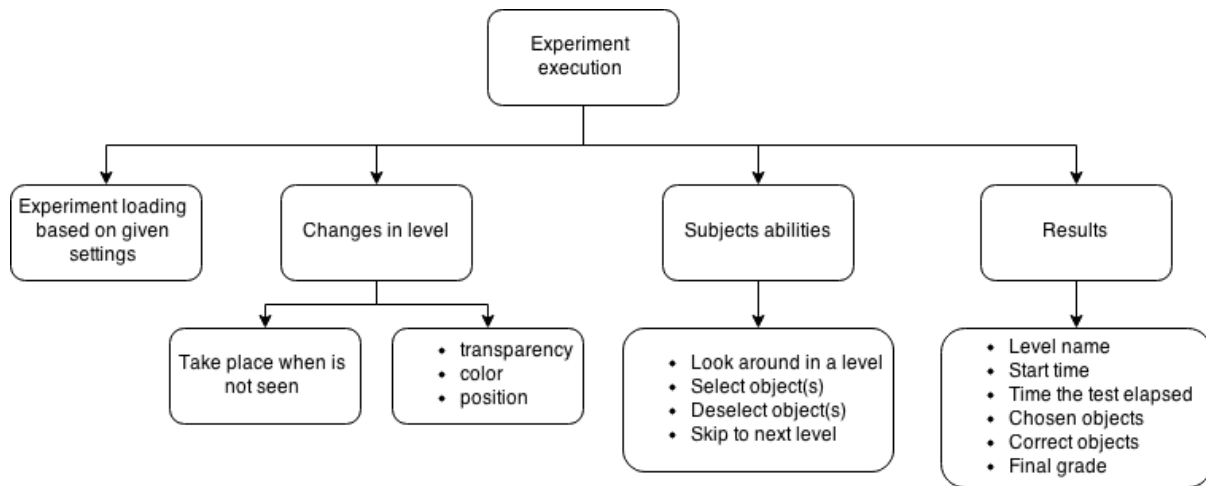


Figure 12: Requirements of experiment execution.

Last but not least, requirements of experiment execution (see figure 12). Change blindness experiments are loaded based on experiment settings and chosen levels. In these experiments object's color, position or transparency may change. A change takes place after the subject has seen changing object and at the moment the subject is looking away from the object. In default changes occur more than once.

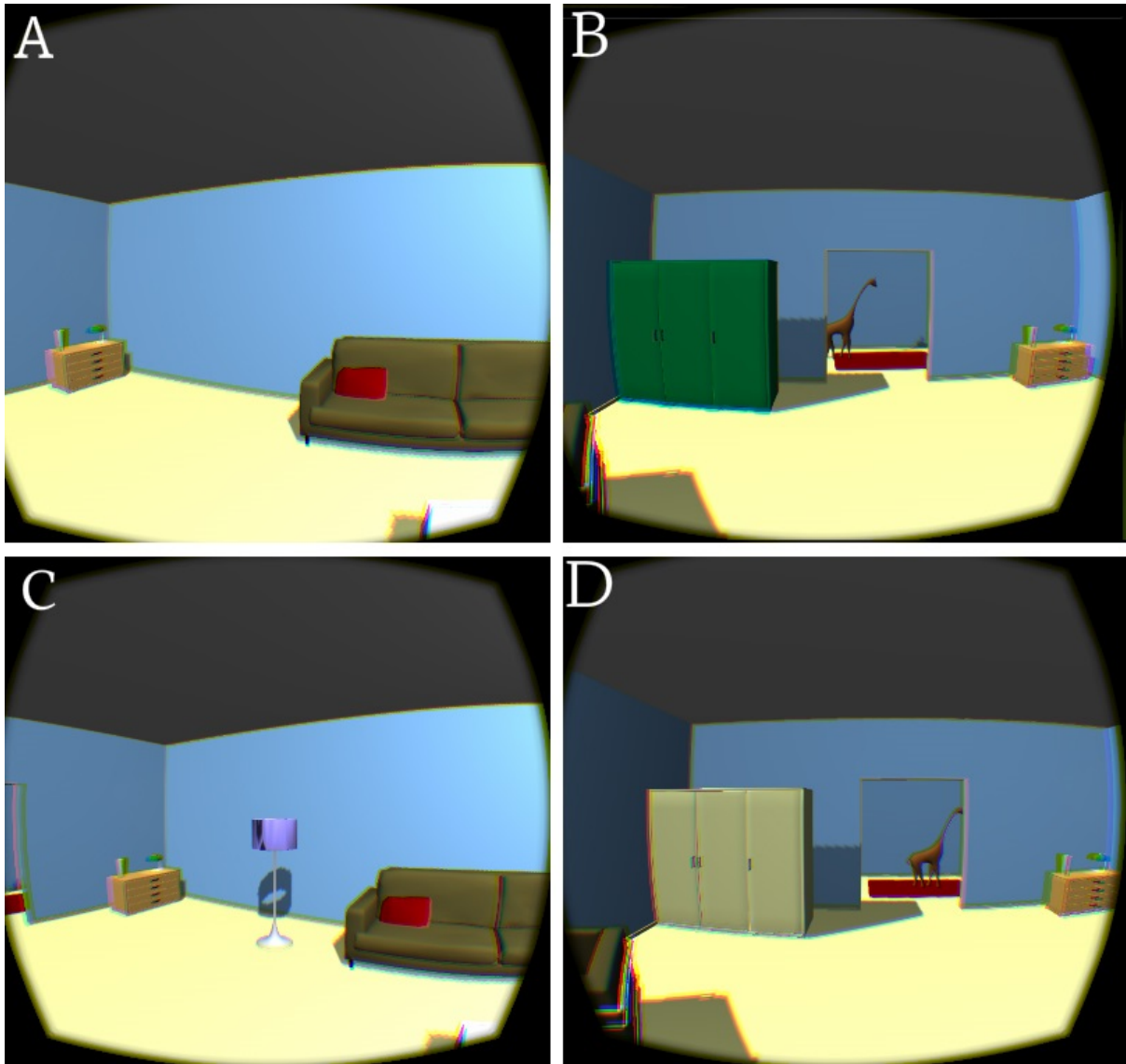


Figure 13: Example pictures of changes. On the first picture (A), program marks changing object as seen (although it is invisible). Then the subject looks left (B) and previously marked object changes. After that, subject turns head right (C) and may notice the change. Also the object is marked again and is ready to change as soon it is not seen anymore.

During a change blindness experiment subject may look freely around the level. Subject also can select or deselect any object in the level and continue to the next level.

Most important in researcher perspective would be saving the results. Results contain level name, changing object names, chosen object names, begin time, how long test elapsed and also how well did subject perform. The results are saved in the end of each level.

## 2.2.2 Non-Functional Requirements

**Performance.** It mainly depends on Unity3D engine and Oculus Rift SDK system requirements, but also on graphical complexity used in level design.

**Usability.** Design and possibilities of the toolbox were discussed with psychology students to get the best result. Users who have experience with Unity3D should find it easy to use. Users with no or little experience should be able to learn quickly how to use the toolbox via help of the user manual.

**Scalability.** Developed toolbox is available on any platform that is supported by Unity3D. For virtual reality experiments Oculus Rift's support is also needed.

**Technologies.** Unity3D gaming engine, Oculus Rift headset.

## 2.3 Technical Side of the Toolbox

### 2.3.1 Framework

The toolbox is made by using Unity3D 4.6 gaming engine. Unity3D was chosen because it is free to use and multiplatform. Most importantly the author of the present thesis had some previous experience with Unity3D and Madis Vasser, who used toolbox's experiment part for his research, worked already with Unity3D.

In addition to Unity3D engine, some premade packages are used. First one is Oculus SDK<sup>2</sup> to get Oculus Rift headset working with the toolbox. Also to add properly working graphical user interface to virtual reality, VRGUI<sup>3</sup> package is used. Finally to add possibility to choose colours, HSVColorpicker<sup>4</sup> is used.

The models used for the toolbox are all free to use and downloaded from Unity3D asset store<sup>5</sup> or blend swap<sup>6</sup>. The authors of the models are brought out in a readme file of the toolbox.

### 2.3.2 Structure

The toolbox contains three main parts, which are divided to scenes. Each of them contains their own scripts and game objects. Keeping the program in smaller functional pieces makes it easier to debug and add new features to it. Some variables are kept between scenes to load the right part from a scene. For example, if user chooses level testing from main menu, level editor scene is loaded and initialised with test view activated. In default user would be sent directly to modifying view.

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<sup>2</sup><https://developer.oculus.com/downloads/>

<sup>3</sup><https://forums.oculus.com/viewtopic.php?t=4944>

<sup>4</sup><https://github.com/judah4/HSV-Color-Picker-Unity>

<sup>5</sup><https://www.assetstore.unity3d.com/en/>

<sup>6</sup><http://www.blendswap.com/>

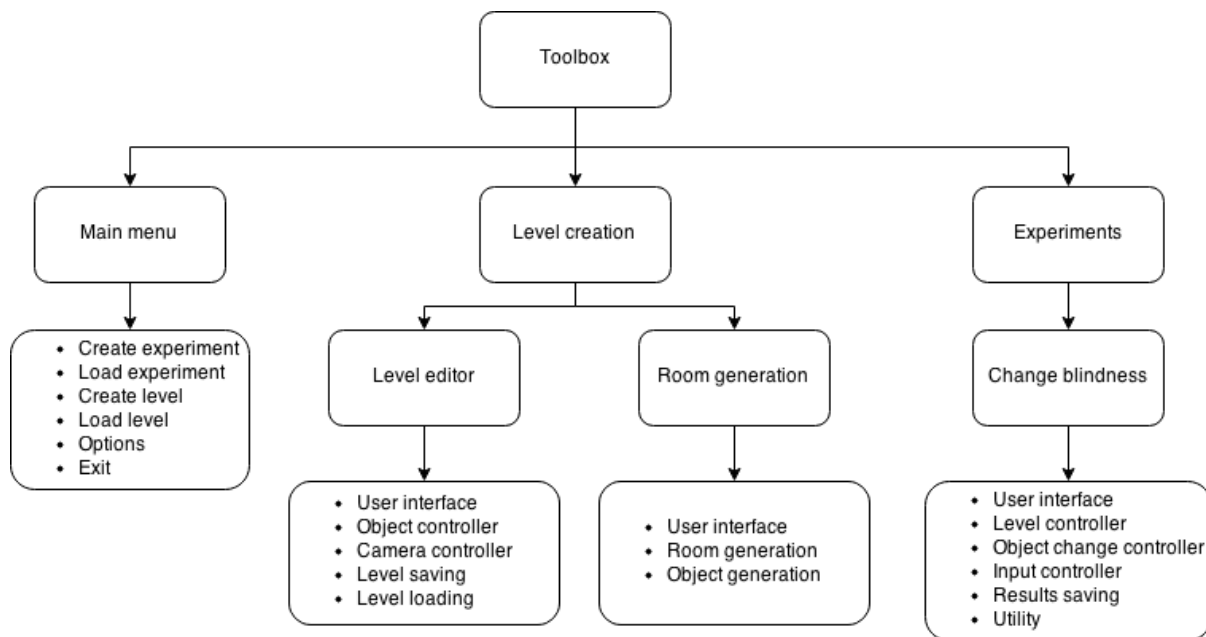


Figure 14: Structure of the toolbox.

First part of the toolbox is the main menu. In essence it contains buttons which lead to other parts. Also via main menu one can create new experiments and modify program settings. More in-depth, main menu contains different UI element groups. For example main menu, create experiment, create level etc. Each of the groups are linked to script that initialises fields and buttons depending on menu functionality.

Second part of the toolbox is level creation. Level creation contains two subparts that are closely linked to each other. The subparts are level editor and room generation. Both of them can be accessed via main menu.

Level editor has its own user interface, object controller, camera controller, level saving and loading scripts. Level editor's user interface is for adding new objects, changing object moving mode, modifying item appearance and position. The object controller handles object moving with direction keys and object selection with mouse. The camera controller allows to move and look around the level to get better perception of it. Also level editor uses shared scripts for level loading and saving.

Level save files contain necessary data to load a level. First row has information about level, its name, creation time and which base was used for it. Following rows have information about the objects, each row for one object. In most of the cases these contain name, original name, position, rotation, scale, colour and tag. However, for an object whose colour or position is changing, another variable is saved.

Room generation has a user interface which allows to select rooms and objects for generation. For main part it has scripts that put the rooms together, depending on room exits, size etc. More detailed description in Kilvits' thesis [26].

Third part of the toolbox are experiments. For each experiment there is a separate scene that contains its information. Change blindness experiment is divided to user interface,

level controller, object change control, input controller, result saving and utility. Its user interface is minimalistic and it is for giving the subject some instructions to get through the levels. Like the name says level loading handles loading part, it loads levels depending on variables read from the experiment file and it keeps track of the level order. Object change control checks whether the object is seen by the subject or not and time between changes is exceeded. If these are both true and object is not in the subject's field of view, a change with the object takes place. Input controller checks for user input. Mainly subject has to press only two buttons, one for confirming and another for canceling. However there is also possibility to skip levels and recentre Oculus camera. Results saving writes a file that contain necessary information for experimenter. For example level name, starting time, changing objects, chosen objects etc.

## 2.4 Example Workflow of the Toolbox

The idea of this chapter is to give illustrated overlook of general workflow of the toolbox.

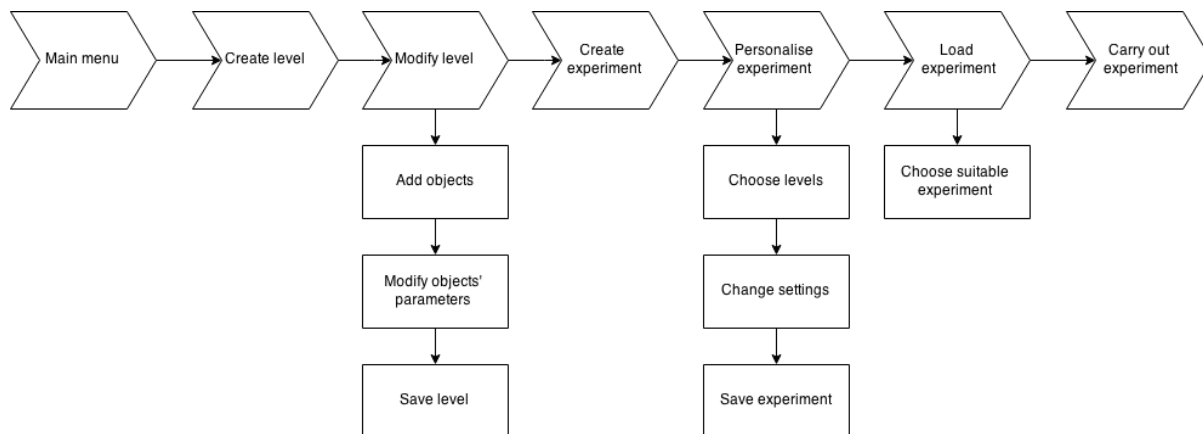


Figure 15: Example work flow of the toolbox.

Firstly a suitable level for change blindness experiment is created. To start with, the level creation menu is opened, then level base is chosen and finally create button is pressed.

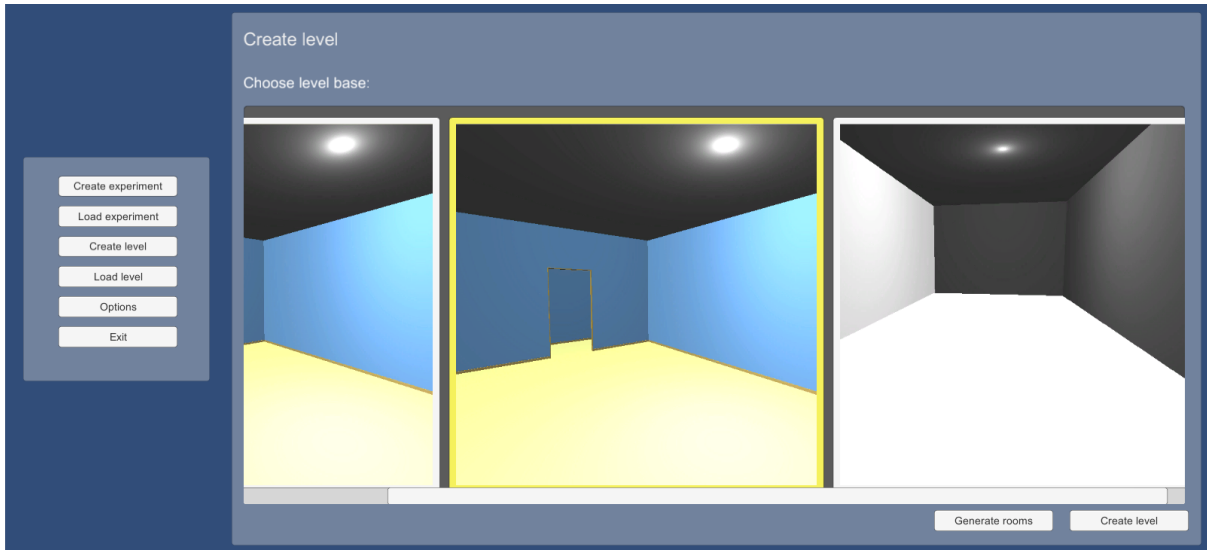


Figure 16: Level creation menu.

Now the toolbox loads the level editor with chosen base.

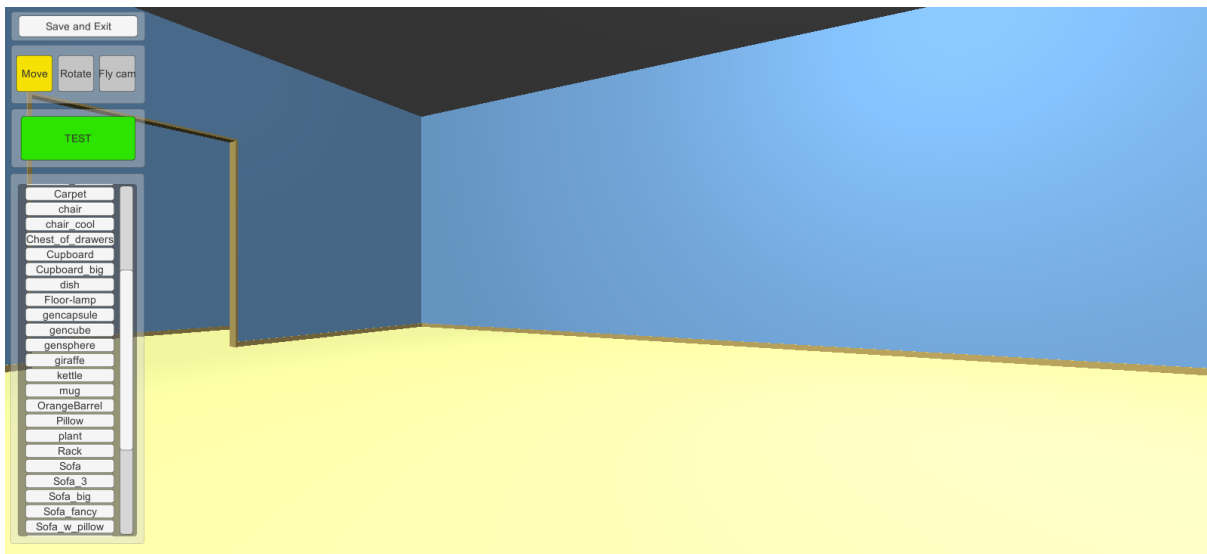


Figure 17: Main view of the level editor.

For the following steps couple of items are added to the level and their appearance and position is modified. Also an object is marked for change blindness experiment.

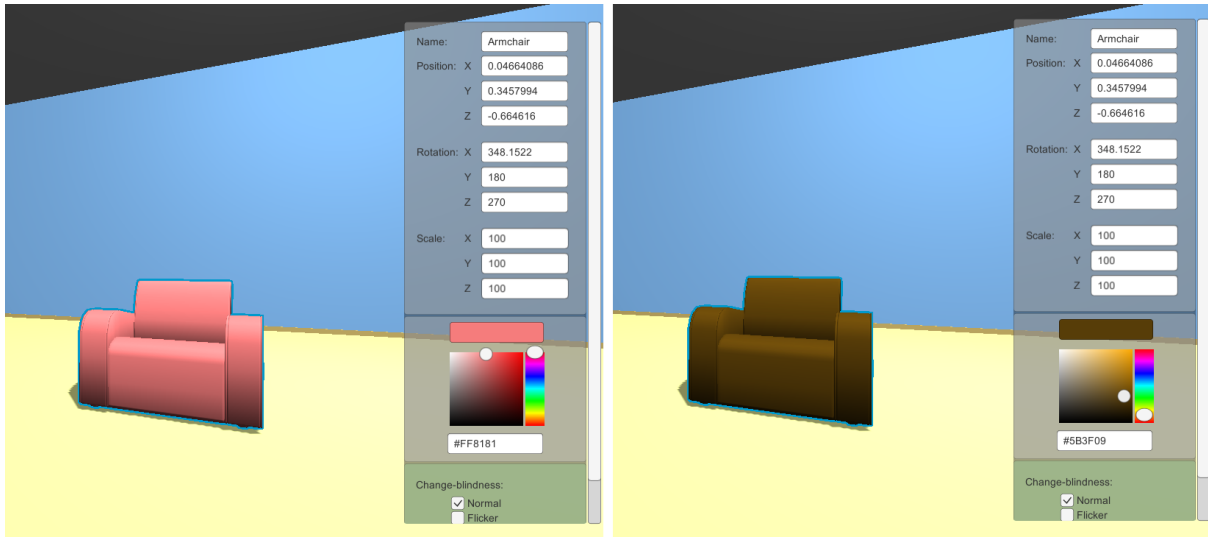


Figure 18: Example pictures of object modifying.

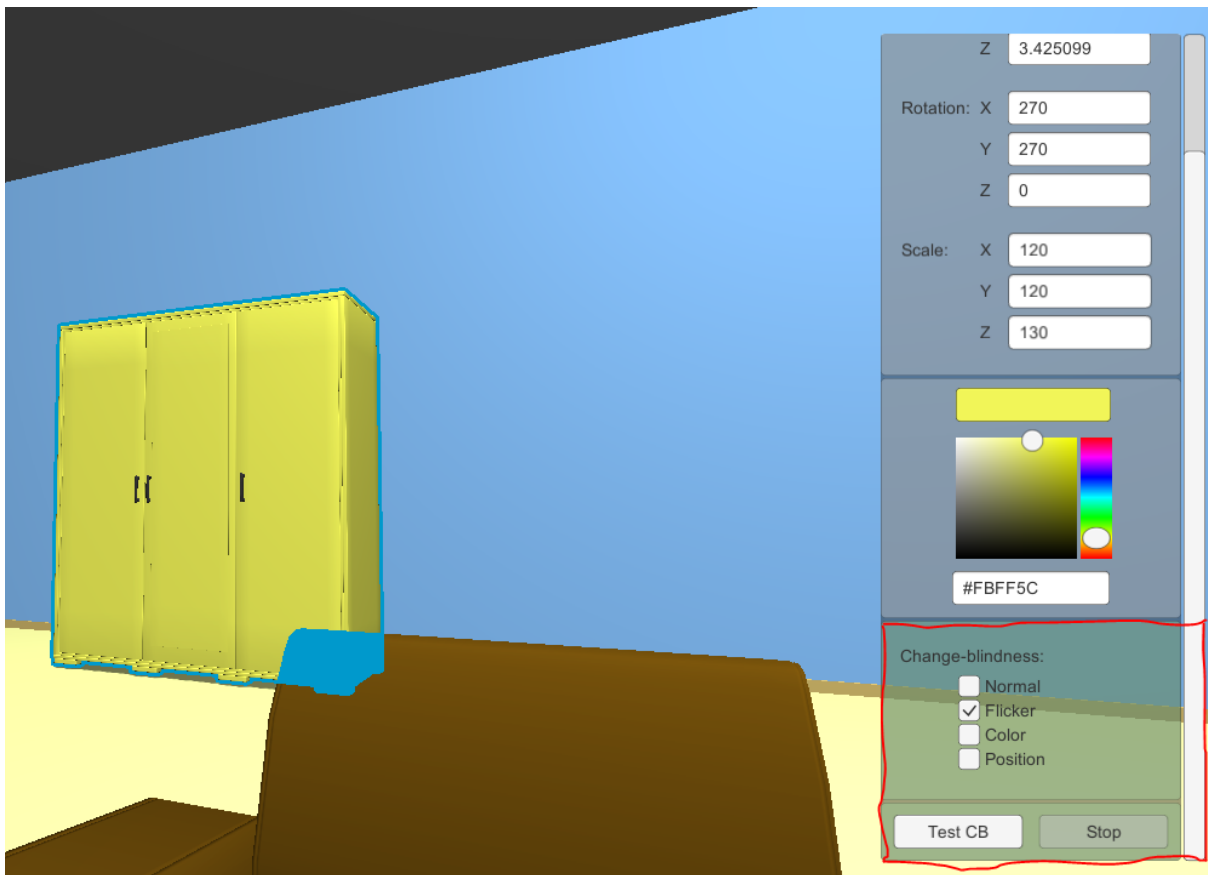


Figure 19: Marking an object for change blindness experiment.

Next the level is going to be tested, whether is suitable or not.



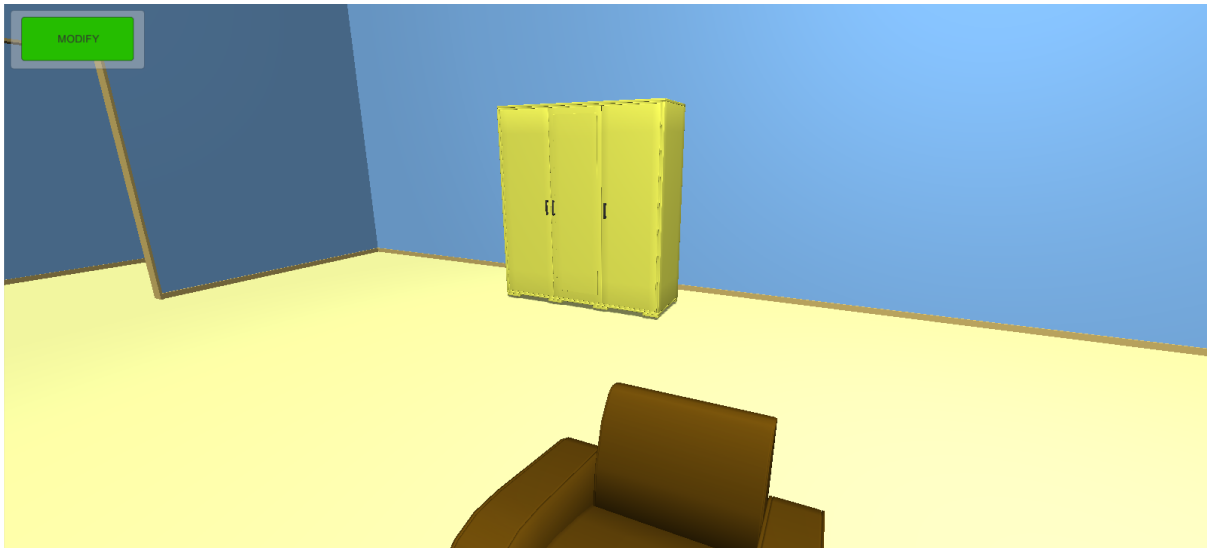


Figure 20: Testing the created level.

For the final step of this part the level is saved.



Figure 21: Saving the created level.

Secondly an experiment is created. For this the experiment creation menu is opened and at least one level is selected and modifiers are changed.

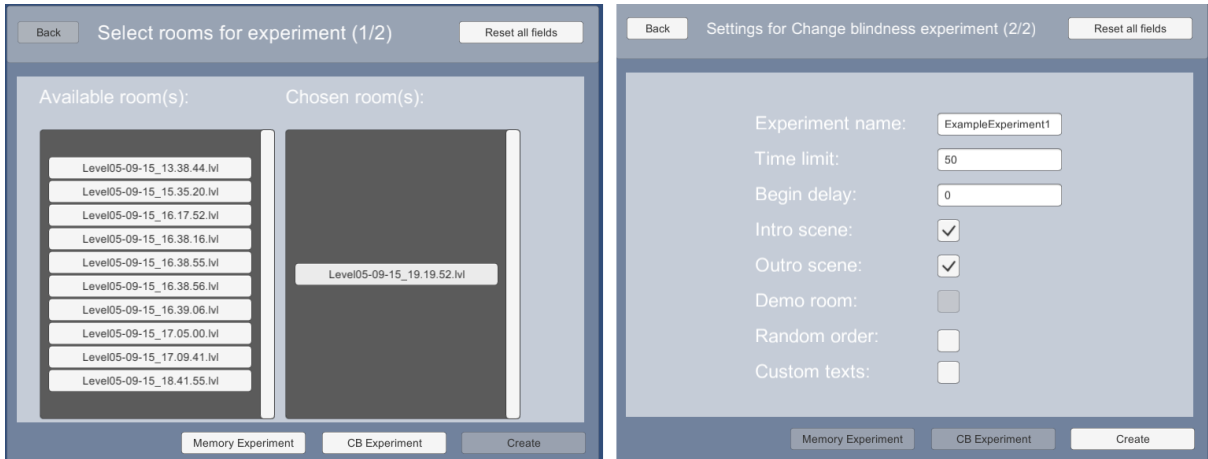


Figure 22: View of level selection and experiment settings.

Next the experiment is saved and confirmation window is closed. Last but not least, the experiment is carried out. For that the experiment is loaded using experiment loading menu.

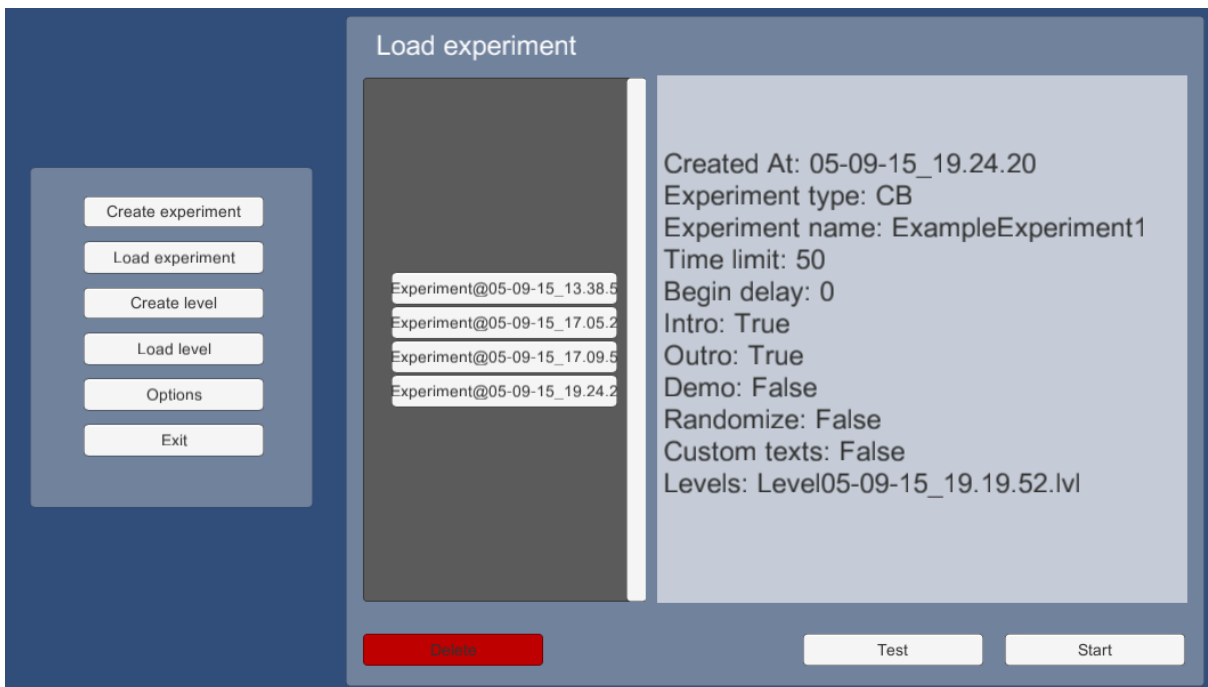


Figure 23: View of experiment loading.

As soon as the experiment is loaded, introductory scene is opened, which displays message prepared by the experimenter. Next a level chosen for the experiment is loaded and the subject may start looking for the change.

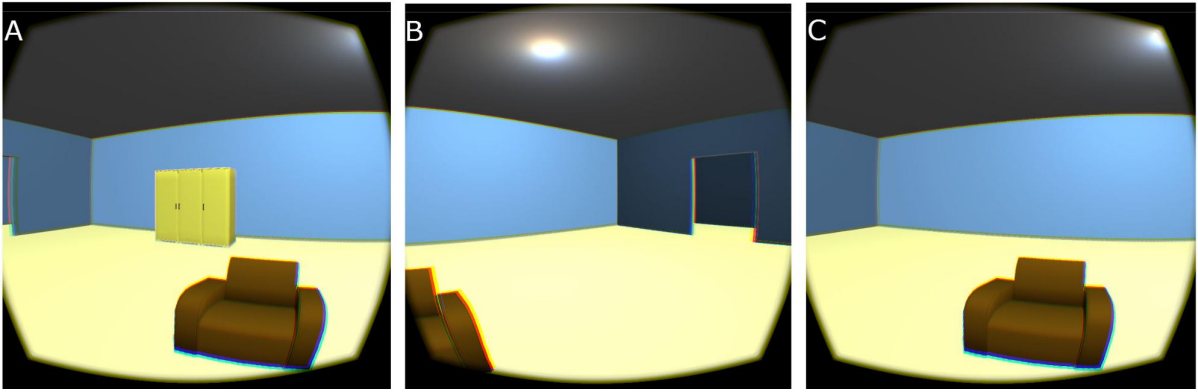


Figure 24: Example of a change. On the first picture (A), the subject looks at a closet, then looks right (B) and finally back at the place, where closet was (C).

When the right item is found it is marked and continued to next level.

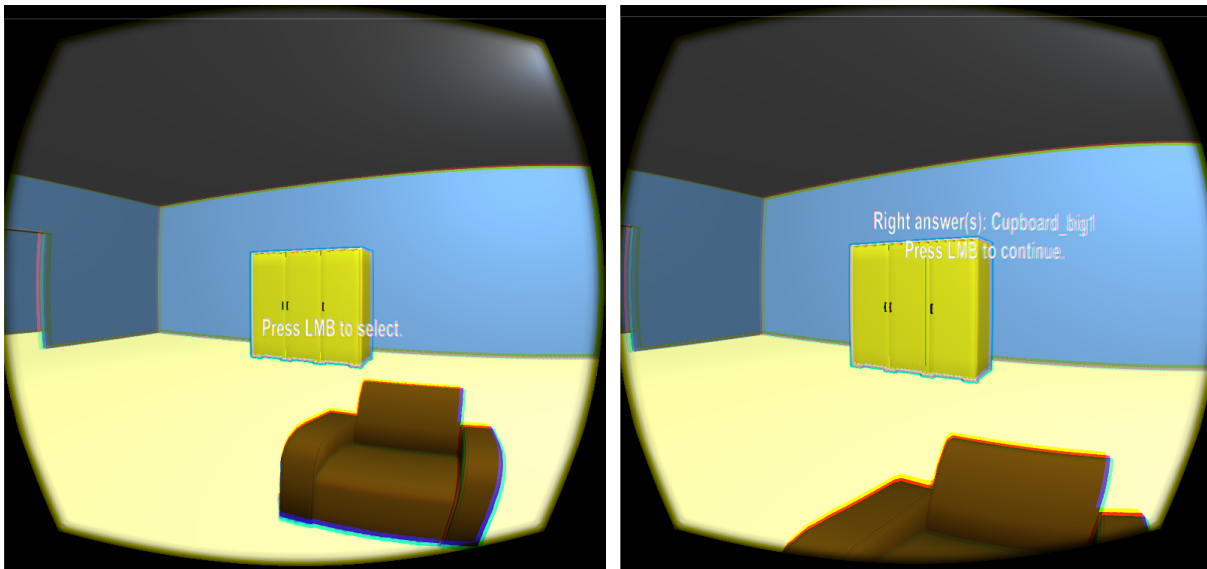


Figure 25: Pictures of object selecting.

After finishing all levels, outro scene is shown.

## 3 General Discussion

### 3.1 Brief Description of the Toolbox

The toolbox enables scientists, interested in change blindness or memory, to design and carry out experiments. To design experiments the toolbox allows one to choose any available level and set experiment variables. For example, level's time limit, whether the level order is randomised or not, are introductions shown before experiment and so on. Furthermore one can modify any level or even create a new level from scratch. Another important part is carrying out experiments. For that the user has to choose a suitable experiment to carry out and press start. The experiment is loaded based on its settings.

### 3.2 Problems with the Toolbox

Most of the encountered problems have been already solved by others. Answers were found from Unity3D official documentation<sup>7</sup>, forum<sup>8</sup>, wiki<sup>9</sup> and answer site<sup>10</sup>.

Although most of the problems were easy to fix and were caused mainly by incompetence and having a little experience with Unity3D, there were some problems which needed further research.

To start with, there was a problem with shaders. To indicate which object was selected by the subject, an outline shader<sup>11</sup> was used. The shader worked fine until baked shadows were used. For some reason the shader refused to add an outline to objects with baked shadows. This problem had a simple solution, using a bumped version of the shader, although it is not clear why that helped.

In addition, there were also problems with designing user interface for virtual reality. First problem was creating a user interface that follows Oculus camera and is always positioned in front of the camera. As a solution the VRGUI package was used, which is a special graphical user interface developed for Oculus Rift.

Second problem was positioning user interface for Oculus Rift. Because it is hard to read text that is near to the ends of screen and also in middle of screen the text may block too much of the view. To make it comfortable for users the positioning had to be tested many times.

### 3.3 Advantages of the VR Toolbox over Conventional Means of Doing Experiments

Virtual reality experiments have advantages over the other methods used for change blindness studies.

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<sup>7</sup><http://docs.unity3d.com/>

<sup>8</sup><http://forum.unity3d.com/>

<sup>9</sup><http://wiki.unity3d.com/>

<sup>10</sup><http://answers.unity3d.com/>

<sup>11</sup>[http://wiki.unity3d.com/index.php/Silhouette-Outlined\\_Diffuse](http://wiki.unity3d.com/index.php/Silhouette-Outlined_Diffuse)

Firstly studies are usually done in two dimensional (2D) way, for example using photos, videos and some virtual environment experiments [7]. On 2D footage it is not possible to determine depth accurately and it is rather hard to get the feeling being in the place by only looking at it. For generating 3D environment head-mounted device (HMD) is used. The only superior way over virtual reality are real life experiments. However, real life experiments bring along many problems. For example, they are difficult to control experimentally and take a lot of resources.

Secondly preparing experiments is easier with the developed toolbox. For example, if a flicker test is planned to be carried out, then photos or videos have to be edited. Moreover in real life experiments there have to be some clever way to distract the subject while the change takes place. However, using the toolbox, a level has to be loaded from available level list (or put together) and suitable objects selected to flicker.

In addition, the new level or new variation of a level can be saved, hence it is easy to reproduce. That can not be said about real life experiments. Complexity of carrying out similar experiments should not be that high, but getting the exact same conditions is pretty much impossible. Also preparing real life rooms for experiments takes valuable time. Also, in real life the study may fail because of human error or uninformed subject might not cooperate. For example, subject's friend may call or something else may distract subject's attention.

Last but not least, in virtual reality subjects are focused on the experiment. Surrounding real world objects are not seen and also not heard, if headphones are used. Having said that subjects have just the amount of distracting factors that experimenters want them to have.

On the other hand, virtual reality experiments are not superior in every aspect. Next some primary disadvantages are mentioned.

To begin with, the devices that simulate virtual reality might not be suitable for everybody. These may cause headaches and nausea [28].

Likewise in other laboratory experiments, subjects are aware that an experiment is being executed, but in real life they usually do not suspect anything.

Finally cost of virtual reality devices is high. In addition, hardware capable of running virtual reality environments is expensive.

### **3.4 Research Carried out with the Toolbox**

As mentioned before, Madis Vasser planned to use the toolbox for carrying out change blindness experiment in virtual reality. For that he used only toolbox's experiment part, because level editor part was not ready. Due to that, Vasser had to use Unity3D to design levels.

The idea of his study [27] was to find out if changes closer to subject are easier to detect

than changes further away. For the study 15 similar rooms were designed, that only had different furnishing. The first three rooms were for getting used to environment and getting hang of the idea that objects change while not looking at them. Results were only gathered for the next 12 rooms, which were randomly ordered. Half of the 12 rooms had changing objects close to subjects and another half further away. For each room subject had 60 seconds to find changing object. To find that object, subject could freely look around the room using Oculus Rift headset.

In total 50 subjects participated in the study from ages 18 to 39. There were 25 females and 25 males. All the subjects had normal or corrected-to-normal vision. 26 subjects had little or average experience with computer games. [27]

As a result 79% of participants detected changes of close objects and 71% noticed objects changing further away. On the other hand, subjects completely failed to identify or misidentified the changed objects in 137 of the 551 trials (24.9%). Furthermore, only 3 of the 50 subjects found changes in all 12 rooms within 60 seconds. Hence, research carried out with the present toolbox demonstrates robust change blindness in 3D virtual environment.

### **3.5 Future Work**

Like for any other application end user is the one who dictates what should be improved and added. However, in the following paragraphs are some ideas to make the toolbox better.

To start with available options of the program should be improved. For example, the number of experiments could be extended by adding greater variety of modifiers, make user interface easier to work with and add more introductions for user.

Furthermore level creating is rather limiting. User can add different objects to a level, but can not create his own level. For this level editor should be improved. For example, adding possibility to create own environments (level bases) and importing additional models.

In addition, more experiment types should be added to the toolbox, because currently it enables to carry out only two types of experiments. To add more experiment types some further research has to be done to find areas of interest.

Another useful feature would be camera logging. That would allow researchers to replay experiments to see how subjects acted. Additionally they could find some proof to speculations and study subjects behaviour more closely.

## 4 Conclusion

Current methods of studying change blindness have various problems. For example, photos and videos are mainly shown in 2D, although humans perceive the world in 3D. In addition, experiments are often hard to prepare and some of them are hard to reproduce or carry out. As a result the toolbox was developed, which makes change blindness studies more realistic as well as easier to prepare and reproduce. To do so, the toolbox allows to design levels and more importantly execute experiments in virtual reality. Additionally the developed toolbox has already been used to carry out a change blindness experiment.

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## A Appendix - The Toolbox

Online additional material of the toolbox will be withheld from publication until 26.06.2016. The material can be accessed using the link <sup>12</sup>.

The online material contains following files:

1. "toolboxfull.7z" - an archive of the toolbox's project files.
2. "toolboxbuild.zip" - the first version of developed toolbox.
3. "User Manual.pdf" - user manual of the toolbox.
4. "Use cases.pdf" - main use cases of the toolbox.

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<sup>12</sup><https://goo.gl/6uTcjr>

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